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The effect of on-deck warm-up routines in baseball on bat velocity, muscular activity and intensity in time-frequency space

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Abstract

The purpose of this study was to determine how using warm-up implements of different weight affects post warm-up baseball bat velocity. Furthermore muscular timing (on-off) and intensity in time-frequency space and thus fatigue were investigated in order to find relations to bat velocity. Four male amateur baseball players participated in this study. On three separate days each subject completed one of three on-deck warm-up conditions (standard (SC), heavy (HC), light (LC)). After each warm-up routine the subjects hit at least five balls with a wood-composite bat (SC). Bat velocity and muscular activity of 16 muscles (8 bilateral) of the upper and lower body were measured. All sEMG data were analyzed for muscular timing using on-off calculations and for intensity in time-frequency space using wavelet analysis. Bat velocity was significantly highest after LC $31.58 \pm 6.78 \text{ ms}^{-1}$. Lowest bat velocity was recorded after SC $22.66 \pm 4.72 \text{ ms}^{-1}$. A muscular recruitment pattern from the lower to the upper extremity according to the kinetic link principle was not retraced. Analysis of the time-frequency domain showed no significant changes in the power spectra after the three warm-up conditions. Hence any indication of muscular fatigue was not detected.

© 2012 Published by Elsevier Ltd. Open access under [CC BY-NC-ND license](https://creativecommons.org/licenses/by-nc-nd/4.0/).**Keywords:** baseball, wavelet-analysis, muscular-timing, warm-up routines

1. Introduction

A fundamental premise of playing successful, offensive baseball is to hit the ball and reach base safely. The most effective way to do so is by hitting the ball out of the playing area (home

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run), thus avoiding any defensive plays. Therefore the hit ball needs to travel at least a distance of 100 meters with sufficient height. A key parameter to achieve such distances is the speed with which the ball is hit and leaves the bat, which is influenced by the hitter's technique and strength [1] as well as the bat's properties. Hence batters strive to increase bat velocity. A common practice, believed by hitters of all skill levels to do so, is to warm-up swinging a weighted bat when preparing for their next at-bat in the on-deck circle. Numerous studies have been conducted in order to investigate the effectiveness of this procedure [2, 3, 4, 5, 6].

The question arises whether a decrease in bat velocity after a weighted on-deck warm-up routine might be caused by a lack of recovery or rest. Following the kinetic link principle, the power necessary to swing a bat is generated in the legs and hips and transmitted throughout the trunk, upper body, arms and finally the hands onto the bat [7, 8]. Few studies investigated this process by detecting the activation levels of various muscles throughout the baseball swing via electromyography (EMG). Most recently [7] conducted a profound EMG study considering twelve muscles (lower extremities, trunk and upper extremities) involved in the baseball swing. These studies confirmed that the baseball swing is a complex movement of coordinated muscular activation though none of these studies investigated muscular coordination by using on-off calculations which are a popular means of studying the timing of muscular events using EMG.

With muscular fatigue possibly playing a role in the decrease of bat velocity after heavy on-deck warm-up swings, EMG provides a commonly used tool to investigate this phenomenon. Changes in the frequency spectrum (median shift) of the myoelectric signal can be caused by fatigue. A commonly used method in EMG fatigue analysis is the fast-fourier transformation (FFT) which allows for the analysis of a signal in the frequency domain. As this method is based on the assumption that the analyzed signal is stationary, its use for the investigation of dynamic contractions is restricted. Recently, wavelet analysis which is a widely used tool for signal processing was introduced to EMG analysis. The wavelet transform allows for the representation of a signal in both time and frequency domain, making fatigue analysis of dynamic contractions possible [9, 10, 11].

The aim of this study was to investigate the acute effect of various on-deck warm-up protocols of baseball players on bat velocity, muscle recruitment patterns and muscular fatigue. It was hypothesized that (H1) a lighter bat during on-deck warm-up results in higher bat velocity, (H2) the order of muscle-onset is performed according to the theory of kinetic link, (H3) the EMG signal in time-frequency domain changes to lower wavelet pseudo-frequencies with heavier bats during on-deck warm-up.

2. Methods

In contrast to previous studies this project aimed at a practical approach to measuring the above mentioned parameters, hence trading the laboratory for the baseball field.

Four male, right-handed amateur baseball players (age: 20.5 ± 0.57 years; height: 183 ± 2.94 cm; mass: 87.5 ± 5.57 kg; baseball playing experience: 14.75 ± 1.5 years) of the Vienna Metrostars Baseball Club (Austrian Baseball League, the highest level of competitive baseball in Austria) served as subjects. At the time of writing all subjects were active members of the Vienna Metrostars' ABL roster. Prior to participating in this study, all subjects read and signed a written consent form, providing information on the experiment's methods and procedures. Each subject was free to end his participation in the study at any time.

Each subject was asked to warm-up and stretch individually in order to prevent any possible injuries. After application of the sEMG electrodes, the subjects were assigned to one of three

on-deck warm-up conditions. Three different bats were used for the on-deck warm-up swings. A wood-composite bat (86.36 cm / 0.88 kg; Pro Maple 110 BLNA34, De Marini Inc., Hillsboro, OR, USA) represented the standard condition (SC). For the heavy on-deck warm-up condition (HC) the SC's bat and another wood-composite bat (83.82cm / 0.85 kg; Pro Maple 243 BLWA33, DeMarini Inc., Hillsboro, OR, USA) were used. The light condition (LC) was defined by swinging an aluminium softball bat (86.36 cm / 0.68 kg; Sc777, Easton-Bells Sports Inc., Van Nuys, CA, USA).

With muscular fatigue being of interest, measurements were conducted on separate days. On each day of measuring, all subjects were assigned to the same warm-up condition. For each condition the subjects then performed three, maximum effort warm-up swings within one minute. After the on-deck warm-up swings, the subjects headed into the batter's box as in a real game-situation. They were then asked to hit at least five rubber practice balls delivered from soft toss with the same bat used for warm-up in SC.

Bat velocity was recorded using two photoelectric sensors (SA1E-PP2-SET, IDEC Elektrotechnik GmbH., Hamburg, GER) mounted on a wooden frame (height of 2 m) pointing downwards with a distance of 30 mm between them.

Five seconds of the myoelectric signal of 16 (8 bilateral, lead and trail) muscles were recorded for each hit with a Myomonitor IV Wireless Transmission & Datalogging System (Delsys Inc., Boston, MA, USA). These muscles were: m. biceps femoris (BF), m. vastus medialis (VM), m. gluteus maximus (GM), m. obliquus externus transversus (OET), m. deltoideus pars clavicularis (DPC), m. pectoralis major (PM), m. triceps brachii caput longum (TBCL), m. flexor carpi radialis (FCR).

As all subjects were right handed, the lead side was defined as the one facing the pitcher's mound with the trail side facing the catcher. The EMG measuring system consisted of 16 DE 2.3 sEMG sensors (electrodes), Dermatode HE-R non-sterile self-adhering electrodes (American Imex, Irvine, CA, USA) (reference electrode), a wearable main unit, two 8 channel input modules and a pouch plus belt.

For EMG data comparison the bat-ball impact was defined as a synchronization event. Both, bat-ball impact and a customized sound emitted by the main unit of the EMG measuring device at the start of each measurement were recorded using microphones (microphone for bat-ball impact: SM 58, Shure Europe GmbH, Eppingen, D; microphone for trigger sound: D M60, Vivanco Gruppe AG, Ahrensburg, D). Both microphones were connected to a notebook's soundcard using an audio interface (Edirol UA 25, Roland Corporation, Japan). Addressing the soundcard via MATLAB 2010a (MathWorks Inc., Natick, MA, USA) the audio signal of the two events was detected at 44000 Hz.

Mean bat velocity of all hits of each of the three on-deck warm-up conditions was calculated. A one-way repeated measures analysis of variance (ANOVA) was conducted to show if significant differences in bat velocity existed between the conditions.

EMG data were reduced to one second by cutting each signal 0.5 seconds before and after bat-ball impact. The cut EMG data were rectified and lowpass filtered with a moving average algorithm (window size 100 ms). On-off calculations were done for all muscles and hits based on a 50% threshold value of maximum innervation level of the filtered sEMG signal. Additionally minimum on-duration of 50 ms was defined. As the generation of bat velocity in terms of the kinetic link principle appears prior to impact, each muscle's first onset was regarded in order to trace the timely firing order of the investigated muscles.

Wavelet analysis was done using MATLAB's Wavelet Toolbox which provides predefined functions for signal analysis. Wavelet coefficients were calculated using the cwt function (con-

Table 1. Pseudo-frequencies (Pseudo-f) and scales (Scales) represented by the nine daughter wavelets (Wavelet)

| Wavelet | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---------------|--------|-----|--------|--------|--------|-----|-------|------|-------|
| Scale | 8 | 10 | 12 | 15 | 19 | 25 | 35 | 52 | 87 |
| Pseudo-f [Hz] | 406.25 | 325 | 270.83 | 216.67 | 171.05 | 130 | 92.86 | 62.5 | 37.36 |

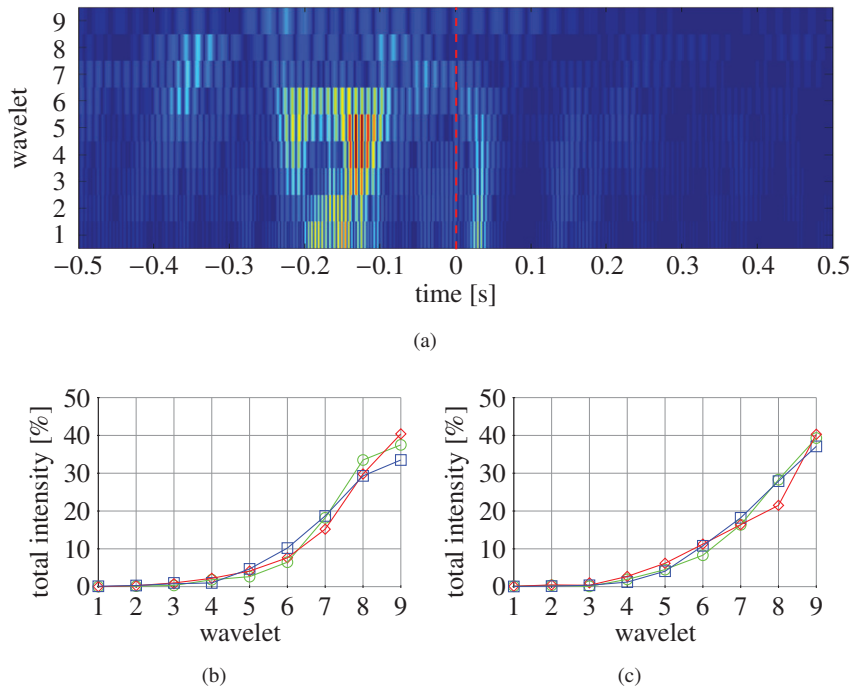


Figure 1. Wavelet analysis plots: (a) Contour plot of the intensity spectrum of the PM lead time-frequency domain in SC condition, red areas show increased activity, blue areas show low activity, the red vertical dashed line marks the time of ball-bat impact; Intensity plots for pectoralis major (b) lead and (c) trail (green circles: SC, red diamonds: HC, blue rectangles: LC). The PM trail was the only muscle investigated, that was found to reveal significant variance in mean intensity. Intensities in the lower frequency domain were higher in SC and HC than in LC.

tinuous wavelet transform) for nine linearly scaled daughter wavelets of a Morlet mother wavelet, each representing a so called pseudo-frequency resulting from the mother wavelet's center frequency and the chosen scales (Table 1).

Summing the squares of the wavelet coefficients for each scale represented the analyzed signal's power (intensity) at each scale. Plotting the intensities for each muscle and scales is called an intensity spectrum. Similar to traditional EMG fatigue analysis by investigating the median shift, a shift of intensity to lower frequencies is regarded as an effect of muscular fatigue. Therefore the mean intensity spectra of the three on-deck warm-up conditions were compared for each muscle. To determine whether any significant change was apparent, analysis of variance (ANOVA) was conducted.

3. Results

Analysis of variance (ANOVA) of bat velocity showed a significant difference in mean bat velocity between the three conditions ($p < 0.0001$, $\alpha = 0.05$). Taking warm-up swings with

Table 2. Muscles are ordered according to the mean time of onset in all three conditions (standard (SC), heavy (HC) and light (LC)), negative numbers signify time before impact [s]. Mean order is the total mean calculated from all trials. Trail side's muscles are marked with an asterisk (*); m. biceps femoris (BF), m. vastus medialis (VM), m. gluteus maximus (GM), m. obliquus externus transversus (OET), m. deltoideus pars clavicularis (DPC), m. pectoralis major (PM), m. triceps brachii caput longum (TBCL), m. flexor carpi radialis (FCR).

| Mean time of onset [s] | | | | | | |
|------------------------|--------------------|--------------|--------------------|--------------|--------------------|------------|
| SC (15 hits) | | HC (22 hits) | | LC (10 hits) | | mean order |
| Muscle | mean \pm std | Muscle | mean \pm std | Muscle | mean \pm std | |
| TBCL | -0.347 \pm 0.029 | DPC | -0.332 \pm 0.076 | DPC | -0.355 \pm 0.118 | TBCL |
| BF | -0.290 \pm 0.129 | TBCL | -0.300 \pm 0.121 | TBCL | -0.351 \pm 0.063 | DPC |
| VM | -0.288 \pm 0.116 | BF* | -0.291 \pm 0.098 | OET* | -0.326 \pm 0.064 | BF* |
| OET* | -0.282 \pm 0.067 | PM* | -0.278 \pm 0.054 | DPC* | -0.302 \pm 0.091 | PM* |
| PM* | -0.274 \pm 0.116 | GM* | -0.254 \pm 0.073 | PM* | -0.282 \pm 0.130 | OED* |
| FCR | -0.274 \pm 0.201 | GM | -0.245 \pm 0.068 | VM | -0.261 \pm 0.198 | VM |
| DPC | -0.262 \pm 0.162 | OET* | -0.230 \pm 0.139 | GM | -0.258 \pm 0.09 | 1BF |
| BF* | -0.257 \pm 0.190 | VM | -0.225 \pm 0.155 | BF | -0.249 \pm 0.086 | GM |
| GM* | -0.249 \pm 0.074 | BF | -0.213 \pm 0.157 | FCR* | -0.235 \pm 0.103 | GM* |
| TBCL* | -0.242 \pm 0.037 | DPC* | -0.192 \pm 0.030 | TBCL* | -0.214 \pm 0.114 | TBCL* |
| GM | -0.238 \pm 0.026 | TBCL* | -0.191 \pm 0.183 | GM* | -0.210 \pm 0.162 | FCR |
| FCR* | -0.175 \pm 0.124 | FCR | -0.168 \pm 0.185 | DPC* | -0.206 \pm 0.048 | DPC* |
| DPC* | -0.160 \pm 0.133 | PM | -0.166 \pm 0.095 | FCR | -0.162 \pm 0.281 | FCR* |
| VM* | -0.147 \pm 0.044 | FCR* | -0.156 \pm 0.135 | PM | -0.161 \pm 0.066 | PM |
| PM | -0.134 \pm 0.184 | VM* | -0.133 \pm 0.111 | VM* | -0.136 \pm 0.031 | VM* |
| OET | -0.062 \pm 0.053 | OET | -0.087 \pm 0.069 | OET | -0.098 \pm 0.168 | OET |

a standard bat (SC) resulted in lowest post-on-deck warm-up bat velocity of $22.66 \pm 4.72 \text{ ms}^{-1}$. In comparison bat velocity was 13% higher after swinging two bats (HC), resulting in a mean bat velocity of $25.83 \pm 4.02 \text{ ms}^{-1}$. Highest bat velocity of $31.58 \pm 6.78 \text{ ms}^{-1}$ was achieved after the light condition. The number of hits taken into consideration for the bat velocity calculation varied between the conditions as not all data were valid (SC: 21 hits, HC: 23 hits, LC: 14 hits).

An overview of the sequences of mean muscular onset as was detected in all subjects for each on-deck warm-up condition is displayed in Table 2. Obviously the sequence of muscular activation varied throughout the three conditions. According to ANOVA this variation was not found to be significant ($p > 0.05$ for all muscles). Overall, the muscles activated first belonged to the upper extremity. All muscles were activated within 0.245 s.

For the wavelet analysis an ANOVA for each muscle and scale revealed that total intensity spectra of the three conditions only changed significantly in the PM trail ($p < 0.02$ for all nine scales). For all muscles investigated, the intensity spectra showed an uncharacteristically reduced high frequency content. Almost no intensity was apparent above 100 Hz which is not typical for sEMG signals (Figure 1).

4. Discussion

Although statistical analysis of bat velocity showed significantly highest bat velocity after the light on-deck warm-up condition, the fact that HC bat velocity was higher than SC bat velocity has to be regarded as rather inconclusive. As bat velocity progressively increased from one

condition to the other, the question arises whether the subjects swung faster as they grew more comfortable with the EMG measurement devices applied. (H1) therefore was not confirmed.

The order of muscular recruitment detected was not coherent to the kinetic link principle as muscular activation was first recorded in the upper extremity, thereby falsifying (H2). It has to be mentioned that onset threshold definition was not done on basis of MVIC normalization which may be more appropriate as it takes the muscular force into consideration. The validity of the methodology used for wavelet analysis is questionable as the use of linearly scaled wavelets for EMG signal processing might be inappropriate [12]. Apart from that no shift of intensity to lower frequencies was detected, indicating that none of the subjects showed signs of muscular fatigue thereby falsifying (H3).

As neither muscular on-off calculations nor the frequency analysis produced significant results, any relation to bat velocity was not investigated. The complexity of this study has to be regarded critically. Further investigations are necessary to evaluate and apply the used methods on a more specific basis and smaller scale.

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